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**Eddy-Current Inspection
for Steam Generator
Tubing Program Quarterly
Progress Report for Period
Ending September 30, 1981**

C. V. Dodd
W. E. Deeds
R. W. McClung

Prepared for the
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
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METALS AND CERAMICS DIVISION

EDDY-CURRENT INSPECTION FOR STEAM GENERATOR TUBING PROGRAM QUARTERLY
PROGRESS REPORT FOR PERIOD ENDING SEPTEMBER 30, 1981

C. V. Dodd, W. E. Deeds, and R. W. McClung

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EDDY-CURRENT INSPECTION FOR STEAM GENERATOR TUBING PROGRAM QUARTERLY
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C. V. Dodd, W. E. Deeds, and R. W. McClung

SUMMARY

Eddy-current methods provide the best in-service inspection of steam generator tubing, but these techniques can produce ambiguity because of the many independent variables that affect the signals. The current development program has used mathematical models and has developed or modified computer programs to design optimum probes, instrumentation, and techniques for multifrequency, multiproperty examinations. Interactive calculations and experimental measurements have been made with the use of modular eddy-current instrumentation and a minicomputer. These establish the coefficients for the complex equations that define the values of the desired properties (and the attainable accuracy) despite changes in other significant variables. The computer programs for calculating the accuracy with which various properties can be measured indicate that the tubing wall thickness and the defect size can be measured much more accurately than is currently required, even when other properties vary. Our experimental measurements have confirmed these results. We have analyzed data taken during scheduled field inspections of the Ginna and Point Beach steam generators and have obtained excellent results. We are also performing tests with pancake probe coils to improve detection of circumferential flaws.

A field test was recently performed at Babcock and Wilcox, Lynchburg, Virginia, on tubing containing intergranular attack. The tubing was extracted from a Ginna steam generator for metallographic examination. We are continuing to improve the equipment and the data-processing systems for field application.

INTRODUCTION

This program was established to develop improved eddy-current techniques and equipment for the in-service inspection of steam generator tubing. Our goal is to separate the effects of variables such as contaminant buildup, denting, probe wobble, tubesheets, tube supports, conductivity variations from defect size and depth, wall thickness variations, and intergranular attack (IGA). Computer design of probes, instrumentation, and techniques is emphasized.

BACKGROUND OF THE ORNL PROGRAM FOR IMPROVED INSPECTION

The ORNL program to develop improved eddy-current in-service inspection for light-water-reactor steam generator tubing consists of design calculations based on theoretical models, construction of optimum equipment, laboratory tests of the best design, and field tests of the equipment. Using models established for eddy-current coils in multiple cylindrical conductors, we calculated the electrical signals produced in the instrument for different frequencies, probe designs, and instrument designs for many test property variations. These variations span the range of those expected in the actual tests. A least squares fit of the test properties to the instrument readings and nonlinear functions of the instrument readings was then carried out. We repeated these calculations a number of times with different coil and instrument parameters until an adequate system was obtained.

We assembled a prototype instrument from modular plug-in components. A probe was constructed, and the instrument was adjusted to conform to the design calculations described above. The instrument was connected to the parallel input-output ports of the ModComp IV minicomputer in the non-destructive testing laboratory. We made readings on tubing test samples that cover the range of anticipated test property variations for the Ginna and Point Beach tests. (Larger denting ranges and other property variations will be run later.) We then did a least squares fit for all the coefficients directly from the experimental data.

Once the optimum coefficients had been determined the process was reversed. Using the new coefficients, the minicomputer continuously took readings, calculated the properties directly, and displayed the results on a CRT terminal in real time. The calculated properties changed in the proper manner as the probe was scanned past defects, tubesheets, tube supports, and thin wall regions. After the instrument successfully passed these tests, its onboard microcomputer was programmed to calculate the properties in place of the ModComp IV, and the instrument was retested. Finally, the instrument was tested in the field at the Ginna and Point Beach reactors and at Babcock and Wilcox, Lynchburg, under actual operating conditions. Changes have been made in the programming to improve the accuracy of the tests, the ease of calibration, and the use of the instrument. The instrument contains an internal passive calibration circuit that is tested against a set of reference standards.

We will write operating instructions and testing procedures.

PROGRESS REPORT DURING QUARTER ENDING SEPTEMBER 30, 1981

We are continuing our task to improve the inspection of steam generator tubing, emphasizing intergranular attack and contaminant buildup in the tubesheet region.

Preliminary results from Babcock and Wilcox indicate that the intergranular attack in the specimens from Ginna is deeper than would be indicated from the sample produced in the laboratory by Pacific Northwest Laboratories. We will wait for the official results from the metallography before we fit our recorded data to the Babcock and Wilcox results.

The drawings for the circuit boards and instrumentation have been updated to the version of the inspection system that was used at Point Beach.

One portion of the task is to develop pancake coils for improved detection of circumferential flaws. Since the pancake coil will be sensitive to only one section of the tubular circumference, it will be necessary for full tubular coverage to provide multicoils in a probe or circumferential motion of a single probe. Parallel activities in a separately funded project are providing significant input into solutions of the problem and are reported here for information.

We are developing techniques with the ORNL modular three-frequency instrument to inspect linear welds in 1.7-mm-thick stainless steel tubing. The system uses a pancake probe coil that is moved back and forth across the weld so that a sinusoidal scanning pattern is provided as linear motion is supplied between the coil and weld. Readings are taken at five different circumferential positions across the weld, and each reading is averaged with the reading at the previous axial position along the weld (not the previous probe position). The steel has an electrical conductivity of 100 $\mu\Omega\text{cm}$ (about that of Inconel 600) and an inner sheath of large twisted copper wires. The multiple-frequency instrument was able to eliminate the signals from the weld variations and the inner conductor and to detect defects 20% of the wall on the inside diameter. Much of the technology and experience with this project can be applied to the pancake probe coil studies for steam generator inspection.

A review of the program was prepared and sent to NRC for the Ninth Water Reactor Safety Research Information Meeting.

The computer program for detecting defects with multiple frequencies in multilayer coaxial cylinders has been modified to permit the use of an absolute coil or coils in a bridge circuit, as well as the previously programmed separate driver and pickup coil arrangement. This permits us to calculate the effects of various coil arrangements to determine which will be most effective for a particular type of measurement.

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